



SiC Megawatt Technology Development Program



# DARPA-EPRI Megawatt Power Electronics

## Program Review

Presented to:

DARPA/EPRI MEGAWATT  
Power Electronics Review

The Hilton Alexandria Mark  
Center

Alexandria, VA

October 17-18, 2000

**NORTHROP GRUMMAN**

*Silicon Power CO*orporation

**kTC**  
k Technology Corporation

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# Thermal Management Analysis, Design and Fabrication Plan for SPCo 200 Amp Package



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## Analysis of SPCo 200 Amp Package

- Model Specifics
  - Both Steady State and Transient Analysis
  - Two Types of Boundary Conditions
    - Forced Convection from Back Face
    - Perimeter (Liquid) Cooling Only
  - Boundary Conditions
    - No Radiation
    - No Convection other than Prescribed
      - $h = 100 \text{ W/m}^2\cdot\text{K}$  on Package Back Surface
      - $h = 1000 \text{ W/m}^2\cdot\text{K}$  on Two Edges
    - 12 GTO's Each Dissipating 50W
    - 108 JFETS's Dissipating No Power

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## Analysis of SPCo 200 Amp Package

- Model Specifics
  - Materials Used in Analysis
    - **Baseline Copper Tungsten (CuW 10:90)**
    - **CuW Encapsulated TPG with Thermal Vias**
  - Geometry
    - **GTO - 2mm X 2mm**
    - **JFET - 1mm X 1mm**
    - **Die Package 30mm X 30mm**
    - **Die Thickness = 0.6mm**
  - Encapsulated TPG
    - 0.1mm CuW foils on 0.5mm TPG

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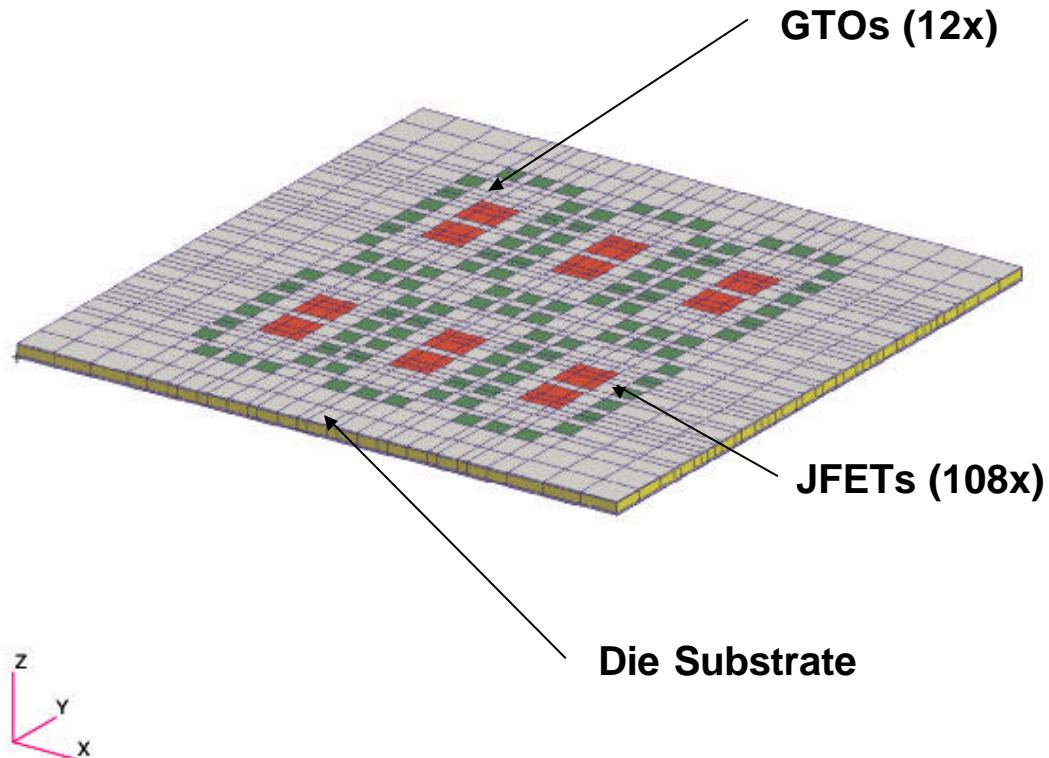
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## Analysis of SPCo 200 Amp Package

- Finite Element Model

- ABAQUS Finite Element Code
- 3D Heat Transfer Element
- 4800 Nodes
- 3393 Elements
- Processed on HP C3000 Platform



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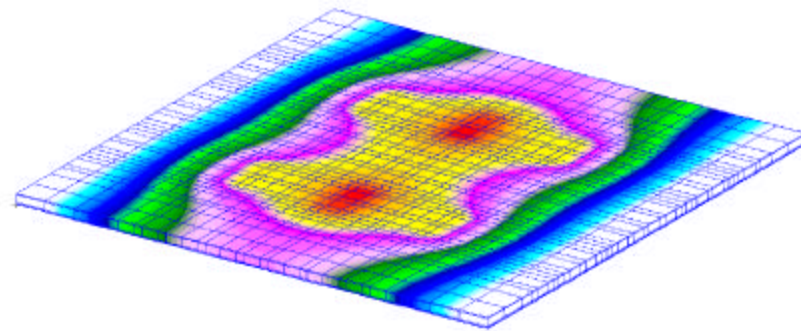


## Steady State Results

- Material - CuW
- Thickness - 0.6mm
- Maximum Temperature
  - 683°C at GTO

MSC/PATRAN Version 5.0 14-Oct-00 12:45:08

Fringe: CuW, Temperature (Nodal), Layer or Section Points, At SECTION\_POINT\_1



default\_Fringe  
Max 683.1 @ Nd 18796  
Min 15.1 @ Nd 1

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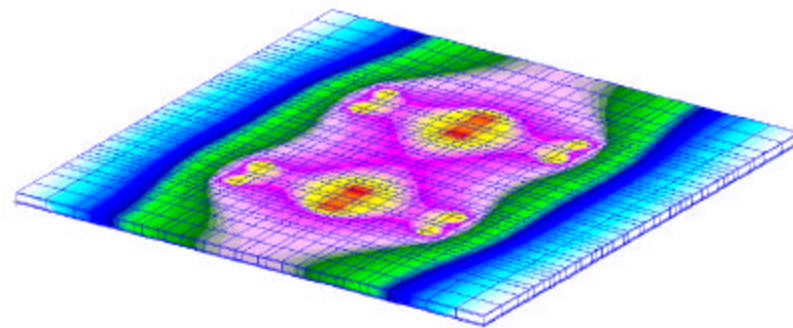
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## Steady State Results

- Material - CuW
- Encapsulated APG
- w/Vias
- Thickness - 0.6mm
- Maximum Temperature
  - 205°C at GTO

MSC/PATRAN Version 8.0 14-Oct-00 12:45:51  
Fringe: APG, Temperature (Nodal), Layer or Section Points, At SECTION\_POINT\_1



default\_Fringe :  
Max 205.0 @Nd 18798  
Min 24.9 @Nd 1

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## Transient Thermal Analysis Results

- **CuW**
  - **Results Show That the Diffusivity of CuW Cannot Efficiently Cool the SPCo Module**
    - **Thermal “Capacity” of CuW Limits Module Efficiency for Cooling**
    - **Thermal Conductivity Limitations Causes Undesired Gradients in the Package**
  - **CuW w/APG Insert**
    - **Analysis Shows >3X Decrease in Operating Temperature Over Solid CuW**
    - **Thermal Diffusivity of CuW/APG Module Will Reach Steady State (Most Efficient) and Will Also Shed All Latent Heat Before Next Cycle**
  - **Maximum Operating Temperatures Will Depend on “Real” Duty Cycle of SPCo Module**

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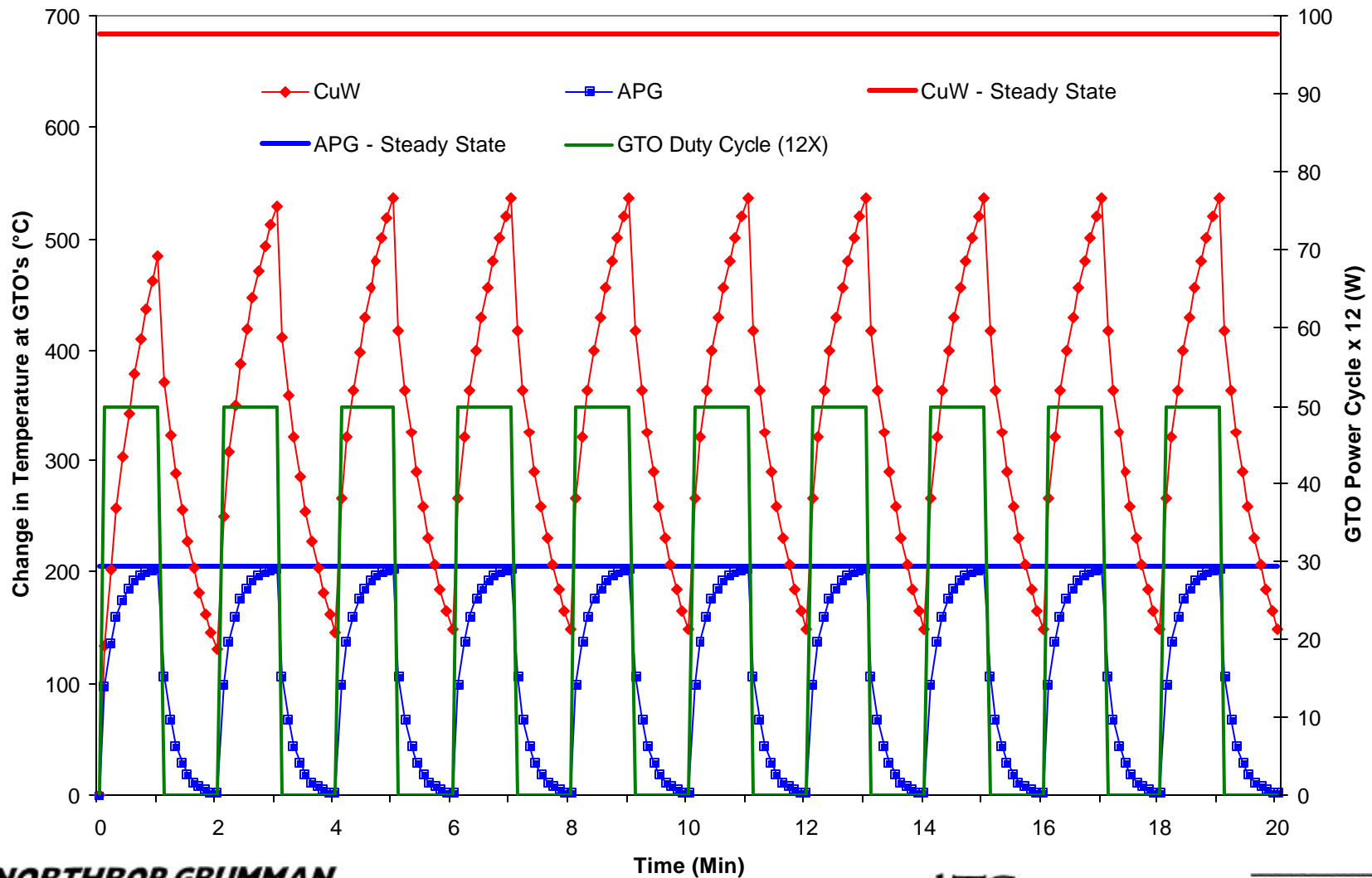
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## Transient Thermal Response CuW Baseline and CuW With APG Insert



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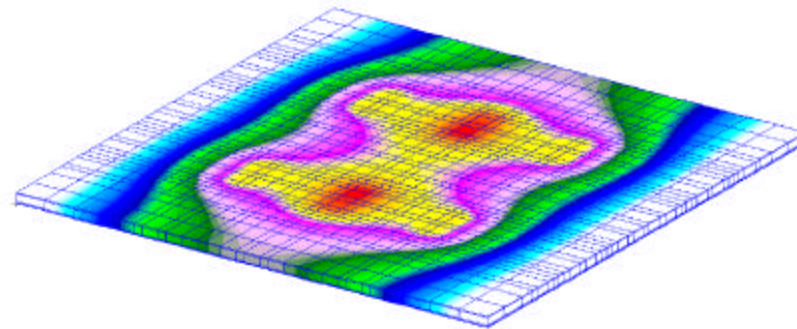


## Transient Results

- Material - CuW
- Thickness - 0.6mm
- Maximum Temperature
  - 536°C at GTO

MSC/PATRAN Version 5.0 14-Oct-00 12:54:10

Fringe: HeatTransfer, Step1, TotalTime=8.. Temperature (Nodal), Layer or Section Points-At SECTION\_POINT\_1



default\_Fringe  
Max 536. @Nd 18796  
Min 10.3 @Nd 1

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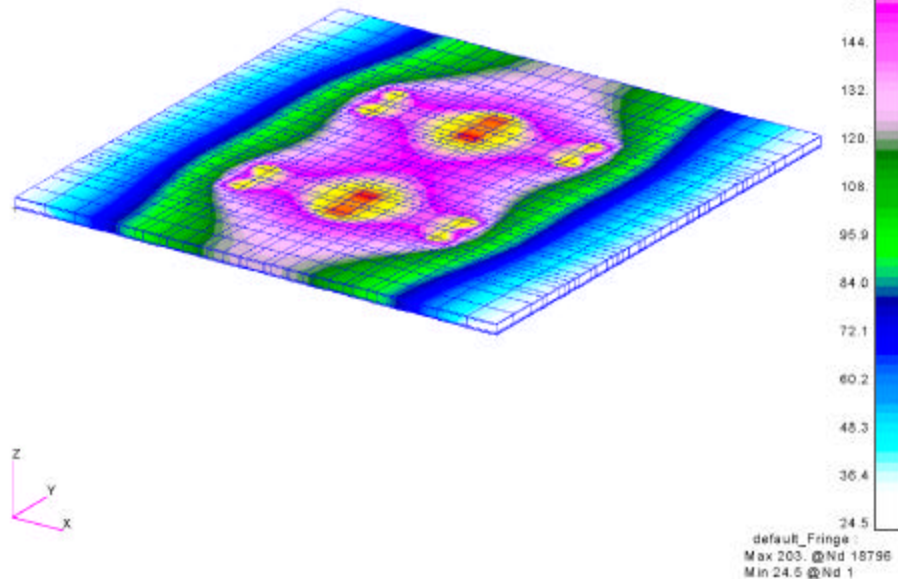


## Transient Results

- Material - CuW
- Encapsulated APG w/Vias
- Thickness - 0.6mm
- Maximum Temperature
  - 203°C at GTO

MSC/PATRAN Version 8.0 14-Oct-00 12:50:44

Fringe: HeatTransfer, Step1, TotalTime=11.: Temperature (Nodal), Layer or Section Points-At SECTION\_POINT\_1



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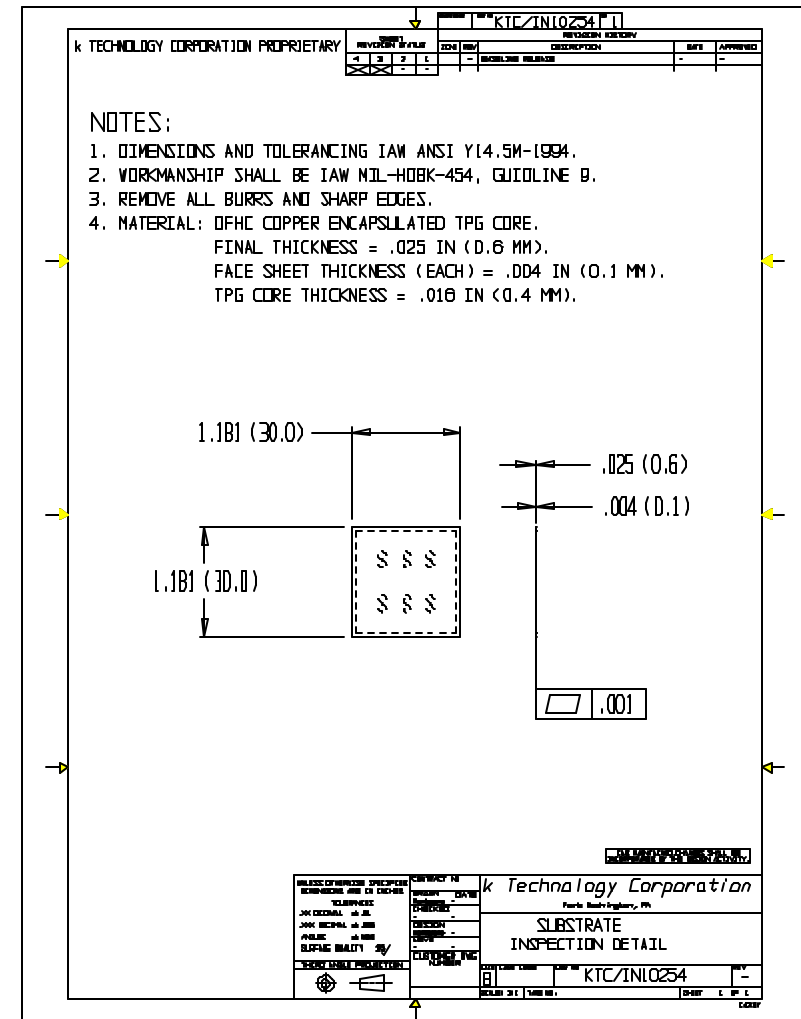
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# Design

- ◆ **Annealed pyrolytic graphite encapsulated with OFHC copper**
- ◆ **Diffusion bonded assembly**
- ◆ **68% APG volume fraction**  
 **$k_x = k_y = 1168 \text{ W/mK}$**
- ◆ **Copper vias place in high through thickness thermal flux regions (under the GTOs)**

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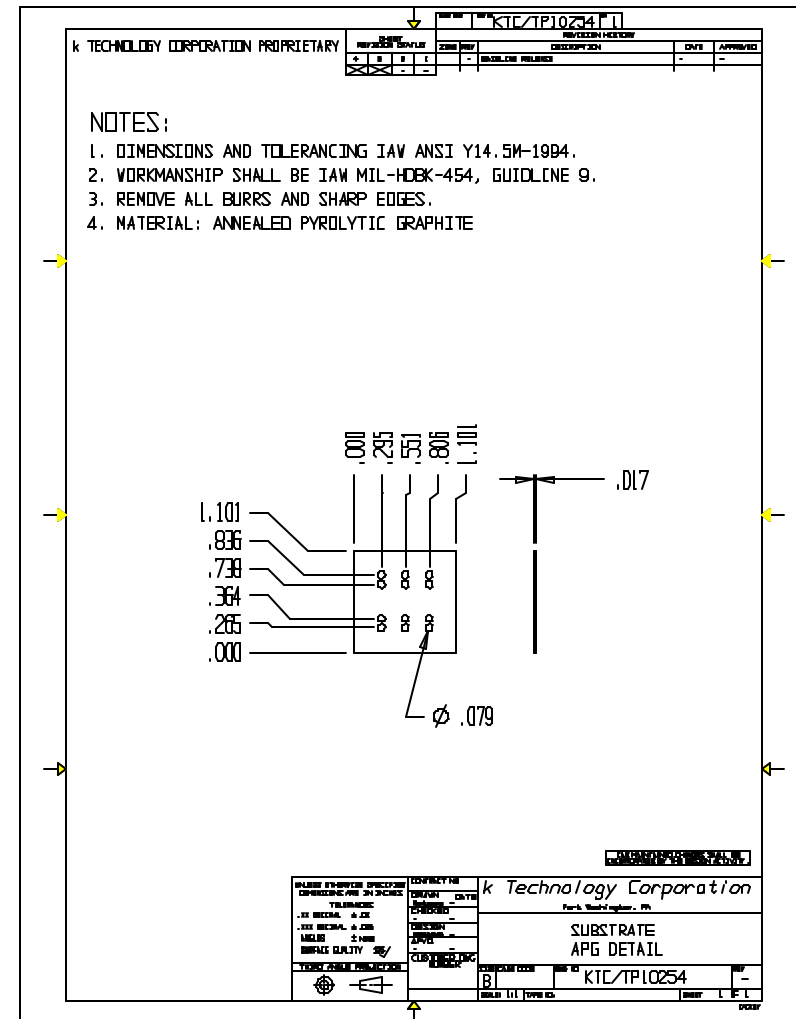
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# Design

- ◆ Annealed pyrolytic graphite (APG) encapsulated insert  
 $k_x = k_y = 1700 \text{ W/mK}$

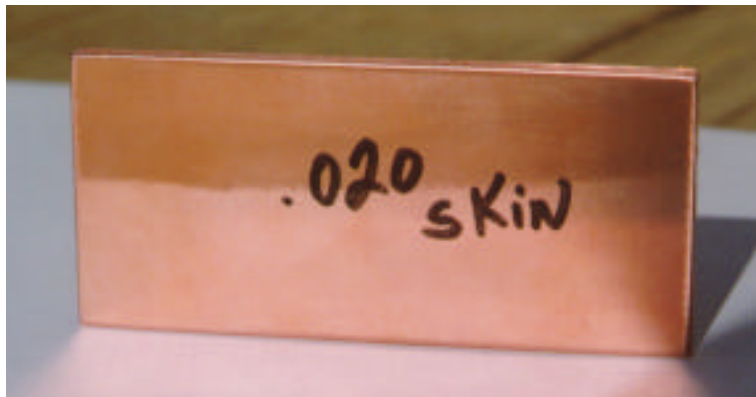




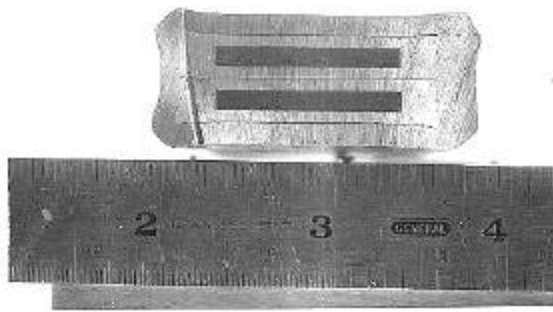
# Fabrication

**Establish the processing parameters of encapsulating APG within copper**

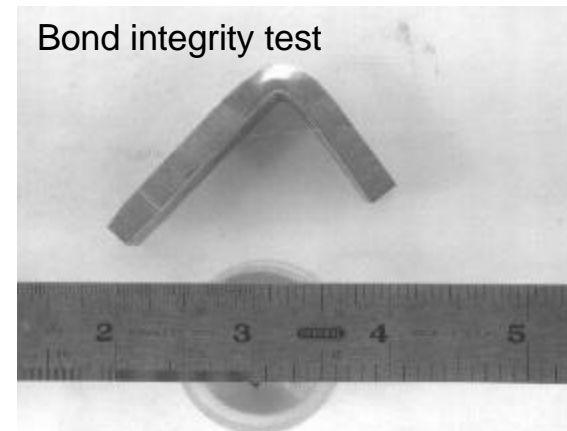
Diffusion bonded copper encapsulated APG coupon



- ◆ Established time/temperature bake-out schedule
- ◆ Established pressure/temperature/time diffusion bonding schedule
- ◆ Evaluated bond integrity



Section view of diffusion bonded coupons



Bond integrity test



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# Fabrication

### Bonding Fixture

SHEET REVISION STATUS				REVISION HISTORY				
REV	DATE	DESCRIPTION	DATE	APPROVED	DATE	DESCRIPTION	DATE	APPROVED
4	3	2	1	-	-	BASING RELEASE	10/19/00	-

K TECHNOLOGY CORPORATION PROPRIETARY

.25" X 2.75" SHOULDER BOLTS  
(REMOVE HEADS)

PLATE -02

KTC/FA10254

PLATE -01

NOTE:  
SHOULDER SCREWS AND ALL SURFACES IN CONTACT WITH COPPER TO BE COVERED WITH GRAPHOIL.

UNLESS OTHERWISE SPECIFIED  
DIMENSIONS ARE IN INCHES

TOLERANCES  
.XX DECIMAL ±.01  
.XXX DECIMAL ±.005  
ANGLES ±.006  
SURFACE QUALITY 12/

THIRD ANGLE PROJECTION

CONTRACT NO.  
DRAWN  
CHECKED  
DESIGN  
APPROVED  
CUSTOMER CING NUMBER

k Technology Corporation  
Fort Washington, PA

FIXTURE  
INSPECTION DETAIL

SIZE DATE DATE DATE NO KTC/FX10254 REV

SCALE 1:1 TAP NO. SHEET 1 OF 3

CADKEY

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## Prototyping Tasks

- ◆ **Final Review of Drawings and Release**
- ◆ **Prepare Pre-bond Assembly Kit**  
(machined APG inserts, machined copper blanks and tooling)
- ◆ **Assembly and Diffusion Bonding**
- ◆ **Final Machining**
- ◆ **Substrate Evaluation**



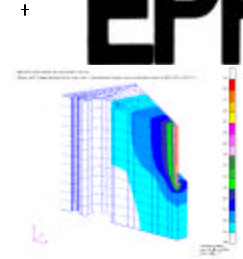
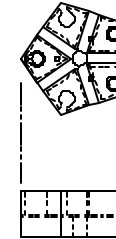


## SiC Megawatt Technology Development Program

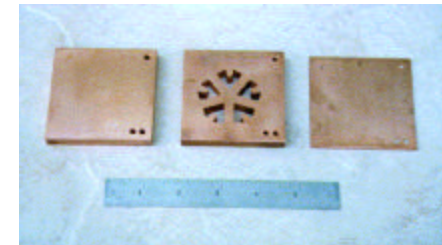
### Spin-off Application

- ◆ Laser Diode Packaging
- ◆ .010" Copper Skin Thickness
- ◆ Three layer design
- ◆ Middle layer contains 5 TPG inserts oriented in x/y plane
- ◆ Assembly will hold 10 laser submounts

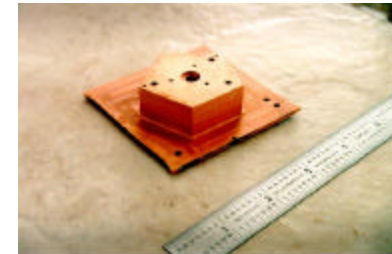
Design &  
Analysis



Pre-Bond Kit



Machining



Inspection



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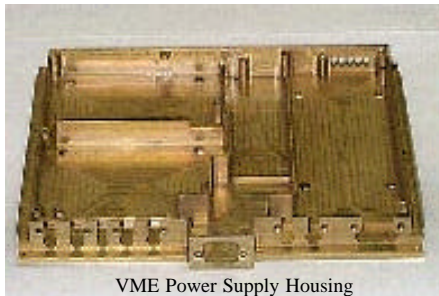


# SiC Megawatt Technology Development Program



## Encapsulated APG Products

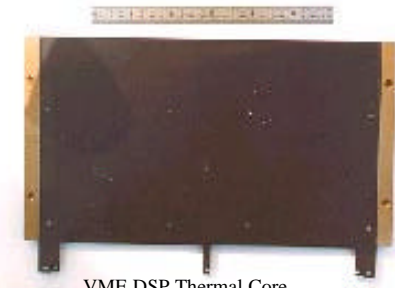
### Thermal Cores



VME Power Supply Housing



SEM-E DSP Thermal Core



VME DSP Thermal Core

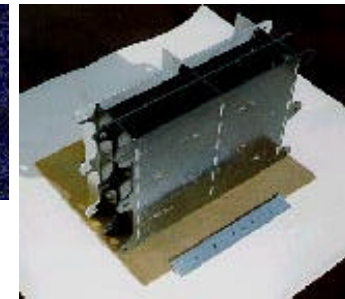


Space Station Power Supply Thermal Core

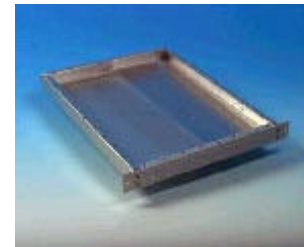
### Chassis/Structures



Ruggedized Commercial VME



Li-ion Battery Bracket



Conduction Cooled Chassis

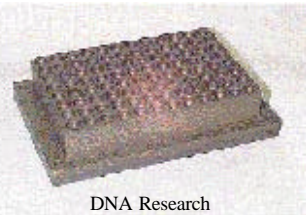


Radiator

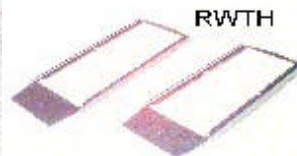
### Heat Spreaders



RF Power-Amplifier Substrate



DNA Research



Particle Physics

### Thermal Management Components



Thermal Strap



Flexible Thermal Foil



APG Platelet Polymer



Leading Edge

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